Spectral Purity Filter Development for EUV HVM

A. Yakunin, V. Banine, ASML
N. Salashchenko, E. Kluenkov, A. Lopatin, V. Luchin, N. Tsybin, IPM
L. Sjmaenok, Phystex
W. Soer, M. Jak, Philips
Outline

- Why SPF?
- Achieved up to now
- New challenges and testing
- How to meet new challenges
- Summary and acknowledgements
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Spectral purity filters for discharge and laser produced plasmas must filter different wavelengths

- Radiation behind Intermediate Focus (IF):
  - DPP:
    - Broad-band EUV
    - DUV-visible-IR
  - LPP:
    - Narrow-band EUV
    - DUV-visible-IR
    - Scattered drive laser radiation (10.6 µm)
- Purpose of the SPF
  - DPP: filtering of DUV
  - LPP: filtering of DUV and scattered drive laser radiation
DUV and drive laser radiation must be filtered for HVM to maintain imaging and overlay specs

- Origin of parasitic out of band (OoB):
  - 10.6 μm CO₂ radiation - partially reflected from plasma
  - 130-400 nm DUV radiation is emitted together with EUV
- Associated challenge from OoB:
  - IR heating of the wafer stage and POB mirrors
  - DUV induced image deterioration

<table>
<thead>
<tr>
<th>Challenge</th>
<th>At wafer</th>
<th>Exceeding requirement by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wafer stage heating</td>
<td>Overlay</td>
<td>5-10x</td>
</tr>
<tr>
<td>POB mirror heating</td>
<td>Overlay</td>
<td>2-5x</td>
</tr>
<tr>
<td>Resist sensitivity to DUV</td>
<td>Imaging</td>
<td>10-30x</td>
</tr>
</tbody>
</table>
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Filtering solution for DUV (without IR) has been previously presented.

Coating on a mirror:
DUV suppression 3-5 x with 7% EUV loss

For higher suppression in DUV multiple mirrors can be coated.
Filtering solution for IR and DUV with a Si/Zr SPF has been previously presented

- Multilayer structure $N = 25$, $h_{Zr} = 1.6$ nm, $h_{Si} = 0.6$ nm $\leftrightarrow$ strength (where $N$-number of layers and $h$ corresponding thicknesses)
- Si $\leftrightarrow$ DUV suppression x1000

- Zr $\leftrightarrow$ High up to 80% EUV transmission

EUVL symposium 2006-2007
Si/Zr SPF under high power exposures in vacuum maintain transmission requirement for ~120 days has been previously demonstrated.

Testing Si/Zr film sample

<table>
<thead>
<tr>
<th>Incident power</th>
<th>W/cm²</th>
<th>0.7</th>
<th>1.1</th>
<th>2.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>days</td>
<td>25</td>
<td>60</td>
<td>37</td>
</tr>
<tr>
<td>Transmission @ 13.5 nm (before)</td>
<td>%</td>
<td>76.53</td>
<td>75.48</td>
<td>74.46</td>
</tr>
<tr>
<td>Transmission @ 13.5 nm (after)</td>
<td>%</td>
<td>76.04</td>
<td>72.25</td>
<td>72.13</td>
</tr>
<tr>
<td>Relative transmission loss</td>
<td>%</td>
<td>0.6</td>
<td>4.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Relative transmission loss %/day</td>
<td></td>
<td>0.026</td>
<td>0.071</td>
<td>0.085</td>
</tr>
<tr>
<td>Extrapolated 10% transmission loss</td>
<td>days</td>
<td>390</td>
<td>140</td>
<td>118</td>
</tr>
</tbody>
</table>

Extrapolated 10% EUV transmission loss ~120 days with corresponding filter temperature of 600 C
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Power load on SPF for LPP is significantly higher than previously expected.

- CO₂ is dominant component in HVM LPP spectrum.
- With about 150 cm² of filter surface the requirement for energy flux is: 3-6 W/cm² with uniform filling for 100+ W at IF.
- New SPF power load target value including scaling and non-uniformity: 20+ W/cm² vs 2+ /cm² before.

For LPP spectrum is filtered by ML-collector:

Significant amount of laser light is scattered and collected:

<table>
<thead>
<tr>
<th>Wavelength name</th>
<th>Power relative to in-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>in-band EUV</td>
<td>1</td>
</tr>
<tr>
<td>out-of-band EUV</td>
<td>1-2</td>
</tr>
<tr>
<td>DUV-IR</td>
<td>0.3-0.7</td>
</tr>
<tr>
<td>IR-scatter</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Akira Endo, et al, EUVL symposium 2006

ASML-ISAN
Test rig has been built for SPF characterization

The purpose:

- Validate SPF performance at higher heat loads than demonstrated previously
- Verify pulsed heat load endurance
Preliminary results from pulsed power load testing does not show additional problems compared to DC testing.

### Pulse power mode heating

<table>
<thead>
<tr>
<th>Gas</th>
<th>Pressure</th>
<th>Power: average / peak</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AU</td>
<td>W/cm²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>240</td>
<td>360</td>
</tr>
<tr>
<td>Background</td>
<td>0.01</td>
<td>318</td>
<td>458</td>
</tr>
<tr>
<td>Gas</td>
<td>1</td>
<td>290</td>
<td>441</td>
</tr>
<tr>
<td>Gas</td>
<td>3</td>
<td>255</td>
<td>420</td>
</tr>
<tr>
<td>Gas</td>
<td>6</td>
<td>220</td>
<td>390</td>
</tr>
<tr>
<td>Gas</td>
<td>10</td>
<td>355</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>100</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>500</td>
<td>155</td>
<td></td>
</tr>
</tbody>
</table>

Peak power during 100 ns pulse $P=360$ W/cm²

### DC versus AC (50 kHz, 100 ns pulse)

- **Gas pressure, AU**
- **Temperature, °C**

- 1.2 W/cm², DC
- 1.8 W/cm², DC
- 1.2 W/cm², pulse
- 1.8 W/cm², pulse
Existing Si/Zr SPF solution needs to be improved

- **Critical parameter:** Filter temperature should be $T \leq 600 \, ^\circ\text{C}$
- Inter-diffusion and silicide formation $\rightarrow$ transparency for DUV and IR

The filter remained mechanically intact (!) but became transparent for IR.
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Several items have been identified for improving the current SPF for the higher power load

- Add effective gas cooling
- Make material improvements:
  - Increase reflectivity of light from the front surface (current reflection is about 50%)
  - Increase emissivity (currently about 30%) for cooling
- Use chemically stable materials
Effectiveness of gas cooling has been tested

With a pressure factor of 100 the acceptable power (<600 °C) can be 12 W/cm², thus 5x scaling with respect to the current performance.
Additional filter optimization is possible

- Decrease of absorption -> 2x
- Increase surface emissivity -> 3x

*Temperature can be reduced (1000 °C -> 530 °C)
Total potential improvement using all options is possible without significant impact to chemical structure of the Si/Zr SPF

- Utilizing all possible options - cooling, improving absorption and emissivity - transmissive filter incident powers of 20+ W/cm² seem to be possible without significant change to chemical structure of the filter

- Additional use of non-chemically active pairs can bring the tolerable temperatures up to 1000-1200 °C and thus to tolerable fluxes ~2x than mentioned above
An alternative grid filter for shielding the CO₂ radiation has been investigated

- Suppression of 10.6μm is as large as 1000x
- A sample of mesh with 80% of geometrical transmission has been made and manufacturability of a large grid is being investigated.
- Due to the chemical stability and reflection of IR, heat balance on the filter is satisfactory
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Summary

- Solutions for SPF both for LPP and DPP have been investigated

- Solutions for DPP are identified:
  - transmissive filter (1000x DUV suppression vs 80% EUV transmission) and
  - special ML coatings (nx3 DUV suppression with 4-5% EUV loss)

- Solutions for LPP are identified and further development is under way:
  - transmissive filter power management and composition improvement is feasible for the required 20+ W/cm² load
  - grid solution satisfies the transmission for IR requirement (0.1%) and the manufacturability on the large scale is being investigated
Acknowledgements

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